Lessons learned from monitoring lighting and daylighting in retrofit projects

T50.D5

A Technical Report of IEA SHC Task 50

19th May, 2016

IEA Solar Heating and Cooling Programme

The Solar Heating and Cooling Programme was founded in 1977 as one of the first multilateral technology initiatives ("Implementing Agreements") of the International Energy Agency. Its mission is *"to enhance collective knowledge and application of solar heating and cooling through international collaboration to reach the goal set in the vision of solar thermal energy meeting 50% of low temperature heating and cooling demand by 2050.*

The members of the Programme collaborate on projects (referred to as "Tasks") in the field of research, development, demonstration (RD&D), and test methods for solar thermal energy and solar buildings.

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- Solar Cooling (Tasks 25, 38, 48, 53)
- Solar Heat or Industrial or Agricultural Processes (Tasks 29, 33, 49)
- Solar District Heating (Tasks 7, 45)
- Solar Buildings/Architecture/Urban Planning (Tasks 8, 11, 12, 13, 20, 22, 23, 28, 37, 40, 41, 47, 51, 52)
- Solar Thermal & PV (Tasks 16, 35)
- Daylighting/Lighting (Tasks 21, 31, 50)
- Materials/Components for Solar Heating and Cooling (Tasks 2, 3, 6, 10, 18, 27, 39)
- Standards, Certification, and Test Methods (Tasks 14, 24, 34, 43)
- Resource Assessment (Tasks 1, 4, 5, 9, 17, 36, 46)
- Storage of Solar Heat (Tasks 7, 32, 42)

In addition to the project work, there are special activities:

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- Workshops and seminars

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Lessons learned from monitoring daylighting in retrofit projects

A Technical Report of Subtask D5 T50

IEA SHC Task 50: Advanced Lighting Solutions for Retrofitting Buildings

April 2016

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PREFACE

Lighting accounts for approximately 19 % (~3000 TWh) of the global electric energy consumption. Without essential changes in policies, markets and practical implementations it is expected to continuously grow despite significant and rapid technical improvements like solid-state lighting, new façade and light management techniques.

With a small volume of new buildings, major lighting energy savings can only be realized by retrofitting the existing building stock. Many countries face the same situation: The majority of the lighting installations are considered to be out of date (older than 25 years). Compared to existing installations, new solutions allow a significant increase in efficiency – easily by a factor of three or more – very often going along with highly interesting payback times. However, lighting refurbishments are still lagging behind compared to what is economically and technically possible and feasible.

IEA SHC Task 50: Advanced Lighting Solutions for Retrofitting Buildings" therefore pursues the goal to accelerate retrofitting of daylighting and electric lighting solutions in the non-residential sector using cost-effective, best practice approaches.

This includes the following activities:

- Develop a sound overview of the lighting retrofit market
- Trigger discussion, initiate revision and enhancement of local and national regulations, certifications and loan programs
- Increase robustness of daylight and electric lighting retrofit approaches technically, ecologically and economically
- Increase understanding of lighting retrofit processes by providing adequate tools for different stakeholders
- Demonstrate state-of-the-art lighting retrofits
- Develop as a joint activity an electronic interactive source book ("Lighting Retrofit Adviser") including design inspirations, design advice, decision tools and design tools

To achieve this goal, the work plan of IEA-Task 50 is organized according to the following four main subtasks, which are interconnected by a joint working group:

Subtask A: Market and Policies
Subtask B: Daylighting and Electric Lighting Solutions
Subtask C: Methods and Tools
Subtask D: Case Studies
Joint Working Group (JWG): Lighting Retrofit Adviser

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1. Introduction

The International Energy Agency launched in 2013 Task 50 entitled ‘Advanced Lighting Solutions for Retrofitting Buildings’ under the umbrella of the Solar Heating and Cooling (SHC) Programme. IEA Task 50, which was completed at the end of 2015 involved 14 participating countries, and pursued the goal to accelerate retrofitting of daylighting and electric lighting in the non-residential sector using cost-effective, best practice approaches applicable to a wide range of typical existing buildings.

This report presents the general lessons learned from the work package on Case Studies called ‘Subtask D’, which aimed to demonstrate sound lighting retrofit solutions in a selection of representative, typical Case Studies spread around the world, see Fig. 1. In order to fulfill this goal, experts involved in Subtask D developed a monitoring protocol applicable to non-residential buildings retrofitted with electric lighting and/or daylighting technologies. This protocol was subsequently tested by monitoring a total of 24 non-residential buildings in ten countries (see table 1).

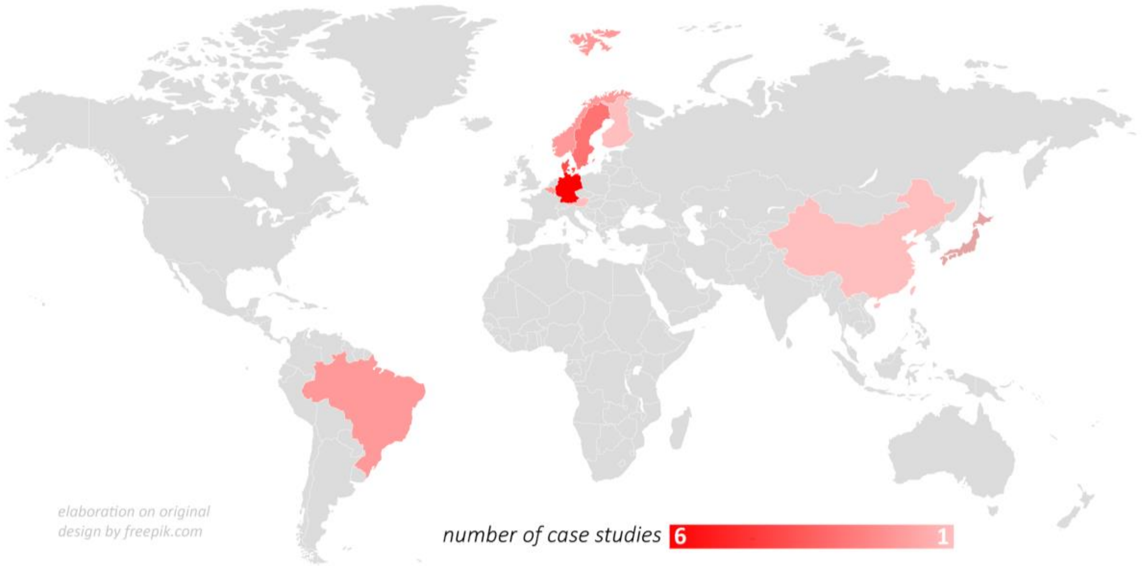

Figure 1: Distribution of case studies around the world.

1.1. Objectives

The aim of this document is to summarize the experience and observations gathered from the monitoring of lighting and daylighting systems and conditions in the case study buildings listed in Table 1.

1.2. Scope and limitations

This document is solely based on observations from the monitoring of the listed buildings. The document is written as an informal collection of observations by the monitoring team, which consists of experts from the IEA Task 50.

Table 1: List of case studies listed by country.

Country	Photo	Case study	Retrofit measure	Building type
AUSTRIA		Bartenbach R&D office, Aldrans	electric/daylight-ing retrofit	Office
BELGIUM		BBRI, Limelette, Wavre	Daylighting and T8 to LED	Office
BELGIUM		BBRI, Sint-Stevens-Woluwe, Lorenzberg	Halogen to LED	Office
BRAZIL		Tribunal of Justice (TJDF-T), Brasília	Shading devices	Office
BRAZIL		Ministry of Environ-ment (MMA), Brasília	Shading devices and T12 to T8	Office
BRAZIL		Ministry of Energy (MME), Brasília	Shading, T12 to T5, daylight controls	Office
CHINA		The National Library of China, Bejing	Shading, T12 to T5, daylight controls	Education
DENMARK		Horsens Town Hall, Horsens	Fluorescent 2700K to LED 6000K + controls	Office
DENMARK		Aarhus University Dental School Clinic	T8 3000K to T5 4000K and daylight controls	Education
DENMARK		Swimming pool and bath 'Spain', Aarhus	Historical building, LED and fluorescent	Sport
FINLAND		Aalto University office, Espoo	T8 to LED with daylight controls	Office
GERMANY		Friedrich-Fröbel School, Olbersdorf	Daylighting systems and controls	Education
GERMANY		DIY Market, Coburg	HMI to LED lighting	Retail
GERMANY		Dietrich Bonhoeffer College, Detmold	Facade renovation and T5 to LED	Education
GERMANY		Flat, Berlin	Incandescent to LED bulbs	Housing
GERMANY		Student Village Schlachtensee, Berlin	Glazing, shadings and incandescent to LED	Housing
GERMANY		Production hall Baden-Württemberg	Rooflight, T8 to LED and controls	Industry
GERMANY		Logistic hall	T8 to LED and day-light-linked controls	Industry
GERMANY		Uhlandschule School, Stuttgart-Rot	T8 to T5 and combined controls	Education
JAPAN		Taisei Technical Center	Fluorescent to LED	Office
NORWAY		Powerhouse Kjørbo, Oslo	Building retrofit to zero emission building	Office
SWEDEN		Architectural School A-hus, Lund	Renovation of interior to higher reflectances	Education
SWEDEN		WSP Headquarter, Stockholm	Enhanced reflectances, T8 to T5 and controls	Office
SWEDEN		High school, Helsingborg	T5 pendants to indirect LED	Education

Colour Key for building types

Industry	Retail	Office	Housing	Sport	Education

1.3. Structure of the document

This report is organized according to retrofit measure applied to the building. After the introduction, the second chapter focuses on daylighting conditions and systems. The third chapter concerns electric lighting systems. The fourth chapter focuses on control systems while the fifth chapter is about interior characteristics. Finally, the last chapter focuses on methodological issues.

2. Daylighting

Nearly all of the selected spaces that have been investigated in the case study buildings receive daylight through windows or skylights. Only two case studies included windowless spaces. In almost all case studies the electric lighting system has been the subject of retrofitting. New controls have been installed in more than 70 % of the cases. Windows and daylighting systems were subject of renovation activities in one third of the case studies. Rooflights were affected in one eighth of the cases. Overall façades, skylights and daylighting systems in 38 % of the cases were subject of refurbishment measures. However, as the aim of optimizing the use of daylight was also followed by measures on interior design and the installation of daylight-responsive controls of electric lighting, daylighting was affected in more than 70% of the case studies.

2.1. Replacement of the Façade

In four of the case studies examined the existing façade was removed and replaced with a new façade. The motivation for the installation of a new façade was primarily to improve the thermal performance of the façade. In the PowerHouse Kjørbo in Sandvika the transparent glass area could be increased slightly by the renovation. In the case of the gymnasium of the vocational college in Detmold the lower part of the façade that was closed by a baffle wall before renovation then was opened. This was possible because the hall is used after renovation no longer for ball sports but as gymnastics hall. The opening of the lower façade region conducted here to an increase in glass area of 38% compared to the façade before refurbishment. In the case of the classroom at the vocational colleges in Detmold and in the case of the classrooms in the attic of the school in Olbersdorf installing a new façade led to a reduction of the glass area as compared to the state before renovation. In Olbersdorf reducing the transparency of the façade was compensated by an additional skylight. In most of the case studies in which the existing façade was replaced by a new façade, triple thermal insulation glazing was installed instead of an uncoated double glazing before refurbishment. In the case of the gym in the vocational college of Detmold in the north façade a single glazing was replaced by triple glazing. The light transmission of the glazing is thereby reduced.

Figure 2: Pre- and post-retrofit of the gym in the vocational college at Detmold

Due to the thickness of the heat insulation layer, the new façade typically has a greater depth compared to the old façade. Especially with small window sizes a greater thickness of the outer wall reduces the transparency of the façade. With a large window dimension this effect is less significant.

However, the change from a double to a triple glazing and increased depth of the construction contribute to reducing the daylight transmission of the facade. When planning a new facade, the existing position and size of the window should not just simply been adopted, but be analyzed and optimized. By using a VIP insulation, a too large total depth of the wall structure can be avoided. The use of large-scale fixed glazing, can be used to reduce the portion of frames and hence optimize light transmission.

2.2. Replacement of windows

In three case study buildings with a total of seven selected spaces new windows were installed and a new heat insulation layer was applied to the façade. Two of these buildings, the student village Schlachtensee and the Friedrich Froebel School in Olbersdorf are listed buildings.

In these buildings special attention was paid to retain the appearance of the façade, and thus not to change the glass area portions. In the student booth of the student village Schlachtensee the renovation led to a slight increase in the glass area by 5%, while the glass area in the standard classroom of the Friedrich Froebel School was decreased by 9%.

The glass area of the overhead window band in the small gym at the vocational college in Detmold was almost halved with the renovation. Here, the insulation of the adjoining flat roof considerably reduced the space available for the construction of the strip-window. Under these circumstances it is considered a success, that the window band could be preserved. Since the lower casing of the window was beveled, for a viewer in the gym the window opening does not appear to be smaller than before the renovation. The windows before renovation typically had uncoated double glazing, while the new windows have a triple low-E glazing.

In the A-building of the University in Lund existing double pane windows were replaced by new triple glazed windows. The characteristic red brick wall of the building was not insulated, the proportion of window area in the renovation therefore remained unchanged.
Since the change from double to triple glazing, the larger window profiles and increasing the thickness of the window wall tend to reduce the daylight level in the space, daylighting should be carefully planned when replacing the windows. Moving the window in the plane of the exterior insulation can contribute to allowing larger window dimensions. Anyway, maintaining the light transmission when exchanging windows to improve the thermal insulation can be considered a success.

2.2. Installation of new rooflights

In three of the case studies buildings new skylight-systems have been installed as part of the refurbishment. In each of these cases the roof was insulated as well. Before renovation the vertical facades in these spaces were not capable of providing sufficient daylight to the space. In the production hall of an engineering company new rooflights were installed with a glazing to floor ratio of 19%. This relatively high corrected opening index was necessary as a light scattering glazing with a special anti-glare film with a light transmission of only 21%, was chosen for vitrification. In the Friedrich Froebel School in Olbersdorf new skylights were installed in the classrooms in the attic and in the gym. Again, the protection from glare played an important role in designing the skylight system. The construction of the light shaft and the selection of materials prevented direct sunlight from falling into the work plane. The glazing to floor area ratio increased from 6% to 17% in classroom 407 and from 6% to 14% in the gym. As a result of the installation of new skylights the use quality in the considered areas could be considerably increased. In areas with deficient daylight supply should therefore also be checked whether the installation of new skylights can contribute to improving the use of daylight.

2.3. Sun shading, glare protection

Nearly one third of the case studies included measures on the daylighting systems. Measures on daylighting systems were almost always combined with measures on the facade or on skylight systems. Only in one case, the research and development office Bartenbach new external shading systems have been installed in front of an existing facade. The office has a bilateral daylighting strategy. On the south facade adjustable horizontal blinds have been installed, the distance of the lamellas becomes larger upward to optimize daylight penetration. The skylight on the north side of the office has been equipped with a fixed external shade that has been optimized for the local sun path. With this combination, the visual link to the exterior was maximized even for sunny conditions.This design provides abounding daylight to the office space while effectively protecting the interior from overheating.

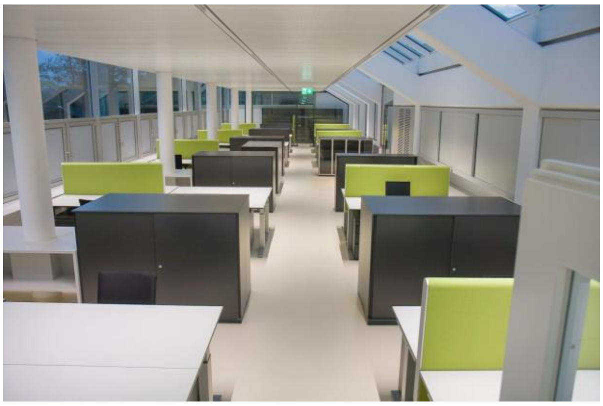

Figure 3: Pre- and post-retrofit of the Bartenbach R&D office in Austria.

In several projects external shades could not be installed or modified for the sake of monument protection. This concerns for example the Ministry of Environment (MMA) and the Department of Energy (MME) in Brazil's capital, Brasilia. Both ministries, designed by Oscar Niemeyer in 1958 as part of the capital plan for Brasilia. They have on the west facade an external shading of vertical blinds, the devices were always closed, obstructing external view and daylighting. On the eastern facade they have no external shading. Inside they are equipped with vertical blinds of fabric to protect from glare. Although the potential to improve the performance has been recognized, the systems were not changed. However, monitoring showed that directionality of the lighting was appropriate in the building. The user surveys indicated unsatisfaction with window size and the transparency of the solar protection after retrofit. Problems like glare and overheating due to sun exposure were not properly solved, causing lower than predicted daylighting use and significantly reduced or completely eliminated views to the exterior for many of the building inhabitants.

Another project, where external solar shading was no option due to the cultural heritage protection was the Friedrich Froebel School in Olbersdorf. Here daylight redirecting louver blinds were integrated in the space of the box window. Windows in areas particularly endangered by overheating received an additional electrochromic glass as solar shading system.

The installation of external shading systems was part of the renovation of the PowerHouse Kjørbo in Sandvika and the classrooms in the vocational college of Detmold. In both cases the buildings were equipped with external shading systems before renovation as well.
In the A-building in Lund in the course of changing the windows from double to triple glazing the venetian blinds previously installed in the space between the glass panes of the double glazing unit were replaced by internal screens.

In the case of the WSP offices in Stockholm Sweden, automated shading screens were installed on the North-East façade. However, employees complained about the noise made by the motors operating the screen.

Even in case studies in which the facade itself was not subject to measures, the existing facade influenced the retrofitting and the assessment of the electric lighting system.

2.4. Interior design

In more than 50% of the case studies, the interior architecture was the subject of retrofitting activities. In the majority of cases the measures primarily served to upgrade the interior design. However, functional objectives regarding daylight were targeted as well.

In the Powerhouse Kjørbo the floor layout was completely redesigned. The depth of individual offices was reduced and a larger area was used for open plan offices and common activities. By opening the space and using lighter colors for the finishings the core of the building appears brighter than before renovation.
In other cases the interior design was changed without tearing off interior walls. In the WSP offices in Stockholm interior obstructions such as cellular meeting rooms were removed and workplaces were rearranged in order to improve daylighting. Like in many other case studies the reflectance of room surfaces has been improved. The use of finishings with a high reflectance is a simple but successful standard measure to improve daylighting.
In the east facing offices of the Ministry of Energy in Brasilia (MME), the internal vertical blinds were renewed and the orientation of the workplaces was changed. A new window in the corridor wall now enables the use of daylight in the corridor, integrated blinds allow to cut the view from the corridor into the offices.
In the Dental school in Aarhus, retrofitting the lighting was combined with a new placement of furniture and repainting the walls. The space thus appeared brighter after renovation.

2.5. Daylight responsive controls

With respect to daylight responsive controls the division of the control areas is of great importance, since the daylight supply level in a control circuit should be as uniform as possible. In the new electric lighting system in the DIY-Market in Coburg daylight-responsive controls have been implemented. Finally this function could not be used because the control circuits included areas of different daylight levels. Therefore the daylight responsive dimming of the electric lighting led in some areas to a too low illuminance. A Complicating factor in the context of defining control circuits in a hardware store are high shelves that prevent the light from spreading around.

Innovative control systems regulate the daylight devices and the electric lighting systems based on comfort and energy efficiency in the building. In the classrooms of the Friedrich-Froebel-School in Olbersdorf such an advanced control strategy was applied. The button "lighting", triggers the activation of controls regarding facade systems and electric lighting. Specifically, this means that compliance with the target illuminance is ensured in the space. This is achieved by the opening of the blinds and adding electric light in case needed. If direct sunlight hits the facade and people are present in the space the louver blinds are moved in a position that no direct sunlight falls into the classroom. Thus, the basic functionality of lighting is delivered, if one activates the button "lighting". Other functions are delivered without intervention of the users. For example if the thermal shading is active the slat angle opens a bit if a person enters to room in order to allow some daylight to penetrate the space.

Figure 4: Interior view of Classroom in the Friedrich-Froebel-School under overcast sky (left) and sunny sky with light-directing blinds (right).

3. Electric lighting

The different case studies in the IEA Task 50 showed that most of the retrofit of the electric lighting system was rather basic and consisted mainly of replacement of luminaires or lamps in the existing luminaires, possibly in combination with a new control system.

In general the retrofit of the electric lighting system in the different case studies improved the luminous environment and energy use, by increased illuminance and/or increased colour temperature and colour rendering and thereby enhanced the user perception and satisfaction.

In addition, the case studies showed that when a control system of the electrical lighting was installed validation of the sensors and a proper commissioning was very important in terms of user satisfaction and energy reduction.

3.1. Replacement

Two cases, one in Denmark and one in Finland, clearly demonstrated high energy savings and user satisfaction with simple electric lighting retrofit.

Horsens Town Hall in Denmark is an example of a basic lighting retrofit where only the electric lighting installation was retrofitted while the daylighting design and lighting controls remained unchanged. Before the final installation with LED panels, an attempt was made to replace the T8 fluorescent lamps and magnetic ballasts in the original luminaires with LED tubes. These lamp replacements reduced energy use by about 55 percent compared to previous levels, but also reduced the illuminance by about the same amount, providing an illumination level below the required 200lx (in Denmark). Furthermore, this created a significantly altered lighting distribution pattern due to the directionality of the LED tubes. For the final retrofit in offices and meeting rooms, LED panels with a color temperature of 5,500 to 6,000K were installed. The new LED panels provided an even illumination and maintained the required illuminance above 200lx for all working areas. The electric lighting was manually controlled via on/off switches installed at the wall near the entrance to each room. To reduce the energy use for the electric lighting system, manual switches were generally provided for each of two luminaire rows parallel to the windows, so the row closer to the window could be turned off when sufficient daylight was present. Despite the quite high correlated color temperature (CCT) of the LED panels, the vast majority of users rated the lighting systems as an improvement over the old fluorescent luminaires.

In Finland, a monitored retrofitted project at Aalto University consisted of six office spaces. The original lighting system of each space consisted of four T8 fluorescent luminaires. During the past years, lamps were substituted many times and also the reflectors were substituted once. All other parts of the luminaires (including ballasts) were original. In two of the rooms, the old luminaires were replaced with new LED luminaires. In two similar rooms, LED luminaires with active dimming were installed. The new luminaires were installed in the same position as the old ones. The active dimming solution used in two of the six rooms consisted of stand-alone built-in dimming solutions for LED luminaires with a photosensor and a presence detection sensor. The installation procedure for the luminaires with active dimming control was exactly the same as for the LED luminaires without a control system. After the retrofit, two energy meters were installed in two rooms to measure the energy consumption of the new lighting systems. The energy consumption before the retrofit was evaluated by measuring the power of the old luminaires and estimating the hours of operation of the luminaires. The luminous environment was assessed by measurements and also simulated with DIALux for both pre- and post-retrofit conditions. User satisfaction was evaluated with questionnaires.

Pre-retrofit lighting conditions did not meet the standard requirements in every room in terms of average illuminance, or in terms of uniformity, or both, depending on the room. After the retrofit, minimum values required by the standards were met. Before the retrofit, the average illuminance was between 180 and 350lx, and after the retrofit it was between 520 and 580lx. Illuminance uniformity increased from 0.5 to 0.8, and the colour rendering index remained almost the same: 84 before and 83 after retrofitting. The Unified Glare Rating (UGR) increased from less than 10 to between 16 and 18, indicating a higher likelihood of experiencing discomfort glare from the new luminaires. Energy savings due to the new luminaires without dimming were 38 percent of the pre-retrofit power consumption, while the new luminaires with active dimming resulted in 68 percent savings. The change in users' satisfaction due to the retrofit was evaluated by comparing the mean ratings of different questions from the pre- and post-retrofit questionnaires. Users evaluated the appearance of the lighting system, of the room, and of the lighting environment, the amount of light, colour naturalness, visibility and visual performance. The results showed that users were more satisfied with the lighting environment after retrofitting.

At the main pool at Swimming and Spa Spain, Aarhus, Denmark, the fluorescent tubes in the original luminaires was replaced with new LED tubes as a part of a larger retrofit. The building and spaces of the Swimming Pool and Spa are heritage protected and the exterior and interior can therefore not be changed. Therefore, the retrofit of the lighting system had to be implemented in the 118 original luminaires. The retrofit caused an increase in colour temperature from 3000K to 5000K that makes the space appear brighter, although the illuminance did not increase significantly.

3.2. Change of amount

At the Horsens Town Hall offices in Denmark, the replacement of the old fluorescent luminaires to LED panels resulted in energy savings, while the illumination was kept as more or less the same. In some offices it was possible with the replacement to reduce the number of luminaires and still keep approximately the same amount of light output. For example at office s.238 (a 2 persons office with a net floor area at approximate 19 m^2) it was possible to reduce the amount of luminaires from nine to four while providing the space with a more even distribution and a brighter appearance.

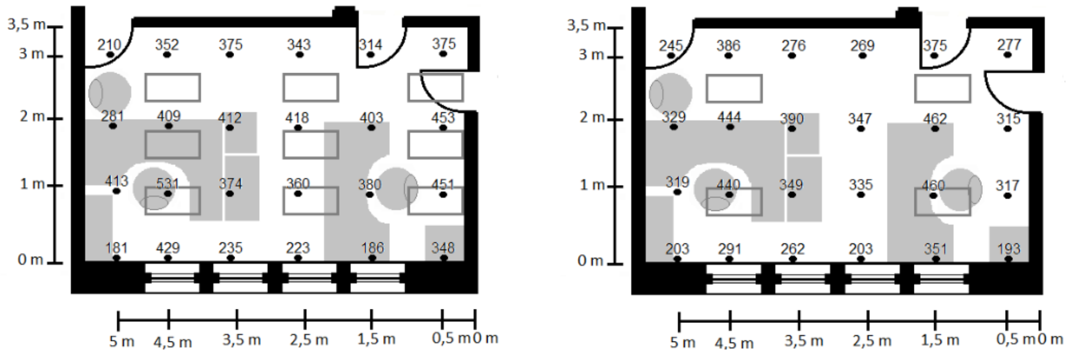

Figure 1: Illuminance distribution from electric lighting system pre- and post-retrofit (right) situations in office s.238 at Horsens Town Hall, Denmark.

3.3. Change of illumination type – indirect fraction

3.4. Change of illumination type – task lighting

3.5. Other electric lighting measures

At the Bartenbach R&D office in Austria, the retrofit integrated electric lighting solution in an efficient tunable white LED downlight system where the color temperature can vary from 2,200 to 5,000K for dynamic scenarios. The dimmable system provides up to 1250lx in every light color at the work plane to also allow biologically activating light. Independent of the selected light color, the energy consumption at 500lx workplane illuminance was below 6 W/m^2.For the morning and evening hours, the highly flexible electric lighting solution produces dynamic scenarios in an attempt to support the human circadian rhythm at highest energy efficiency. The integrated control reacts to exterior and interior conditions to intelligently combine the daylight and electric lighting solution and provide a pleasant lighting experience.

The lighting retrofit in the offices consisting of replacement of the old fluorescent luminaires with new LED panels caused an increased colour temperature at approximately 3000K-6000K and a more even distribution which created a brighter luminous environment although the illuminance was kept at the same level. The occupants were in general satisfied with the new lighting system although a dimmable control system would have been preferable. Especially during wintertime where the high colour temperature can appear very bright against the low exterior illuminance.

4. Control

Control systems are in general installed to maintain a pleasant lighting environment and at the same time reduce energy use by providing a sufficient illumination through dimming or turning on/off the lighting system.

The control systems can be provided in different ways, with more or less user interaction, but in all cases it is of great importance that the sensors and the control system is properly validated and commissioned after taken into use. Otherwise the likelihood that the lighting system will not fulfil the users' needs and instead cause dissatisfaction. In the case of strong dissatisfaction, the control system will most likely be sabotaged by the building manager or the users and thereby lead to an increase in energy use.

4.1. Integration between daylighting and electric lighting

The results of the monitoring in the Tribunal of Justice of Federal District and Territories (TJDF-T) - Brasília showed that despite the fact that this was a building with high daylighting potential, the electric lighting controls were not linked with daylighting, which had negative consequences for energy efficiency.
However, in the Ministry of Energy building, a daylight responsive control system is installed near the facades, allowing a better control of electrical lighting and consequently a more pleasant lighting environment as well as higher energy efficiency. This system controls only some luminaires, combined with other kind of controls in the rest of the room.

At the Dental School of Aarhus University, Denmark, the retrofit of the electrical lighting involved daylight-linked control system to maintain the illuminance at 1000 lux, needed at Dental Clinics according Danish Standards, and reduce the energy use of electric lighting. The space is divided into three control zones where only the zone close to the windows is provided with daylight-linked dimming. All three zones are linked to occupant sensors.

4.2. Type of control

Occupancy strategy for private lighting
In the case of the WSP office in Stockholm, Sweden, the personal ceiling mounted pendant had a built-in occupancy sensor. The installer left the setting on "presence" (automatic switch on-off) and 15 minutes time-delay. The sensor's field-of-view was too wide, so any person passing by would trigger the switch of several fixtures. This was very annoying and the employees did not know how to change it since the building manager was difficult to reach. The lesson learned from this case is that

absence strategy and narrower field of view should be preferred for lighting in landscape offices.

Daylight-linked control system
In the case of the Dentistry School Clinic at Aarhus University, Denmark, a daylight-linked dimming system was installed. However, the installed sensors and their set points adjusted the illuminance level far too often and thereby caused discomfort and annoyance for the occupants. As repeated attempts by the electrical company supplying the system failed to correct the problems, it ultimately resulted in the sensor illuminance set-point being adjusted to its highest level, so that no dimming occurred. Because of this, projected energy savings were not achieved. This also outlines the necessity for properly commissioning the building shortly after the retrofit is completed.

Manual control
Both at the offices at Horsens Town Hall and in the main pool at Swimming Pool and Spa Spain, Aarhus, Denmark, the electric lighting systems were manually controlled by switches. The electrical lighting system at Horsens Town Hall are only controlled by on/off switches, which are provided for each of the two rows in the spaces, so it is possible turn off the row closest to the windows when there is enough daylight. In general, the lighting system is fulfilling the users' needs although many users would like the possibility to dim the light output, especially during wintertime when the high colour temperature yields a huge contrast with the outside.

In the main pool at Swimming Pool and Spa Spain, the electrical lighting is dimmable which can be controlled manually. Though the illuminance is rather low in the space the lighting system is never at maximum output, since this creates too many reflectances at the water surface and thereby makes it hard to see the bottom of the pool thereby creating a visually unpleasant luminous environment since the water surface is constantly in movement. But overall the control system in the main pool is fulfilling the workers and the bathers needs.

4.3. Other light management measures

At the Merchant Bath at the Swimming Pool and Spa, Spain, Aarhus, Denmark, the electrical lighting is controlled automatically by a preprogrammed schedule, but can be overruled manually by the building manager. The illumination from the electrical lighting system is provided by 14 ceiling mounted luminaires with compact fluorescent tubes and additionally coloured light at the different spa pools. The coloured lighting at the different pools are mounted below the water surfaces in the sidewalls of the pools. The coloured lighting are only on during the opening hours and is automatically programmed to be turned off in the middle of the day and in the evening hours when the Merchant Bath closes. The general lighting is likewise pre-programmed to automatically be turned on and off. But in contrary to the coloured lighting the general lighting is on during the closed hours in the middle of the day and some hours after evening closing, to provide sufficient lighting for the people who clean the space.

In general, from Brazilian cases the conclusions are that with a good integrated control system, appropriate to the case, it is possible to achieve all the potential of energy efficiency. Between the three analysed cases the best result was obtained in Ministry of Energy (MME), both in energy efficiency of lighting and user´s satisfaction. The automation of lighting system in this building provides to user the possibility of dimming each luminaire, combined with a daylight responsible system in some places. This sophisticated system allows good

daylight use and also the adaptation of lighting system to personal needs, which leads to a 9% economy compared with original lighting system without controls.
But the ideal situation, as is showed in the cases of Ministry of Environment (MMA) and Ministry of Energy (MME) would be to have total integration between daylighting, electric lighting and solar protection elements (vertical fins in West facade in this case). In heritage buildings with one integrated system it would be possible to optimize all controls without any changes in facades (moving the existing fins according to the sun). In fact, on these two buildings (MMA and MME) problems with glare and solar gains were detected, because the solar protection systems are not easily movable by users.

5. Interior

The use of materials and colours in interiors may have a strong impact on the light level. Generally, the lighter the room surfaces are, the higher the light level. In the case of daylighting this rule is especially important for a room illuminated only from one side.

5.1. Repainting surfaces

Probably the cheapest way of increasing light level working with interiors is simply repainting interior surfaces. The WSP case study showed an improvement in daylighting with a white painted back wall (about 91% reflectance), which replaced the old dark red wall (about 25% reflectance). These measures brought the daylight factor to values higher than 2 percent in the post-retrofit situation. The use of electric lighting during the day was sporadic, even for the working stations far from windows, which brought energy savings.

On the other side, it has to be mentioned that the white colour may not be always acceptable nor desired by occupants as it may create an impression of a neutral, cold and inpersonal space. An alternative to white can be a very light chromatic colour. Even a very small addition of a chromatic pigment in the paint is easily noticeable by the human eye and may change the impression of the space significantly.

5.2. Interior design

At the Bartenbach R&D office in Austria (Fig. 2), the interior of the office was redesigned making use of lower partition heights, bright surfaces and an acoustical ceiling. The overall retrofit solution provides a highly daylit building with hardly any need for additional electric lighting during daytime hours.

(right)
As a part of the general retrofit of the Dental School at Aarhus University, Denmark, was the interior was retrofitted with new and lighter coloured furniture and the walls were repainted. Together with the new lighting system, the repainted walls and the new furniture are making the space appear brighter. Despite the high illuminance (1000 lux),the space were still perceived as very pleasant and not too bright.

In the case of the Powerhouse Kjørbo in Norway, a thorough renovation was achieved, enabling radical changes of interiors that contributed strongly to increase the daylight levels.

The old suspended ceiling was removed leaving concrete slabs exposed, something that helped to even the temperature variations throughout the day. The concrete slabs were painted a white colour (about 80% reflectance).

Even more interesting is the redesign of the layout of the office areas. Partition walls surrounding the original cell offices were removed. In more than half of the occupied office area, the space was kept open enabling a better distribution of daylight and enabling an improved visual contact between occupants. The office landscape created in this way needed new acoustic attenuation. This was achieved by a highly innovative technology, i.e. baffles in the ceiling and lamellas on the core walls made of recycled plastic bottles. The acoustic elements have white surface colour with the reflection factor close to 90%. New cell offices were also built in the rest of the office space, with white walls, furniture and ceiling and with glazed doors that enable the penetration of daylight from cell offices to the communication areas.

5.3. Other interior measures

Any object located in the pathway of light rays contributes to the reduction of light levels in a room. In the case of daylight from windows, removing the flowerpots, curtains or decorations from the window surface proved to be a very reasonable decision, for example in the NTNU-case. Also large box like luminaires positioned under the skylights, as it was in the NTNU-case, obstruct daylight. After moving them to the side, a significant improvement of daylight level in the room was noticed.

It is important to avoid positioning luminaires above or very close to ventilation ducts or other building elements to avoid obstruction of light. This may be obvious, but it happens all too often in real buildings.

6. Lessons learned from the monitoring process

When monitoring case studies of lighting retrofit, it can be expected that the monitoring process will take place over a longer period of time, since, if possible, the measurements should be performed both before and after the retrofit. In general, the full set of measurements is quite time-consuming and often intrusive for the building occupants. Therefore, it is recommended to use only parts of the described monitoring protocol and the desired outcome of the monitoring procedure should be carefully planned in the start phase, to decide which measurements are necessary to carry out in order to avoid unnecessarily measurements and disruptions of the building occupants. It is therefore recommendable to plan the monitoring procedure in relation to the Initial Visit Survey (IVS) and carefully discuss the timeline and measurement strategy with the building manager, in order to reconciliation of expectations of the measurement sessions. Although the monitoring protocol in most cases was fully implemented, the analysis of results showed, that only a part of the information achieved by monitoring was used. Hence one should tailor the protocol with respect to each specific project.

It is important to clarify how much the measurements are allowed to interfere with the occupants, for example whether it is possible to hand out questionnaires, how often they can be handed out and which form would result in most answers. It should also be clarified whether it is possible to talk with the occupants about the lighting environment during the measurements or if this will be perceived as a distraction.

It should be carefully arranged with the building manager when possible to carry out the monitoring session and make sure that the occupants are notified in advance in order to avoid annoyance from the occupants.

6.1. Timing and weather conditions

The measurements of daylighting were difficult to achieve in practice since on the planned monitoring day, the weather conditions were not as expected. For example the daylight factor can only be measured under overcast skies. This was especially problematic when the monitored building was very remote from the work place of the monitoring team. Last minute cancellations and travel costs were significant in this case. One way to go around this problem is to plan several measuring days in advance and make sure that there is measuring staff available in the city where the building is located. In any case, this issue should be addressed with the building manager at the beginning of the monitoring process, preferably already during the IVS, to allow for some flexibility in the monitoring schedules.

6.2. Privacy issues

In general, the IEA T50 experts found that some of the measurements were slightly intrusive for the building occupants. For example, measuring the lighting conditions provided only by daylight may not be possible in some buildings since turning off the electrical lighting system may influence the occupational safety. Since the monitored buildings are typically occupied, it is necessary to have a close collaboration with the building manager to have access to the environment and make occupants feel at ease and as little disturbed as possible on the monitoring day. Monitoring procedures can also interfere with expectations of confidentiality for both building owners and users. Such concerns should be discussed when initiating a monitoring process and an agreement about how to treat potentially sensitive data should be made.

6.3. Measurement technique

The authors found that some measurements were very time consuming and required a significant familiarity with instrumentation and the monitoring process. For example, measuring directionality was found to be difficult, and it was discarded by many experts during the monitoring process since it was often too time consuming. In addition, the measurement of energy use was often problematic since electric lighting circuits are not provided with a separate electricity meter in most buildings. In these cases, energy use had to be estimated based on information about lighting fixtures and occupancy patterns.

6.3. User assessments

During monitoring sessions of the IEA Task 50 the user aspects have mainly been evaluated through the General Lighting Questionnaire which was developed as a part of the monitoring procedure. However, in many cases it can be worthwhile to ask the users during the measurement sessions, in addition, how they perceive the lighting environment and systems, how they interact with them and if they fulfil their needs. This will in most cases give a more varied and in depth description than what might be described in the survey. Additionally, the questionnaire should not be too long and not handed out more often than necessary in order to avoid survey fatigue and thereby reduce the amount of answers.

The form of user questionnaire may influence the amount of answers of the survey. In many cases an electronic survey can be recommended since this form will save the monitoring team time to transcribe the answers afterwards. Additionally, in many work environments, the workers are spending a large part of the working hours in front of a computer and therefore an electronic survey may be easier to be filled out than one on paper.

Alhough an electronic survey may save time for the monitoring team, this will not always be the best way to ensure most answers from the occupants since some work environments are not computer-based. For example employees in industry, retail stores and sports facilities may not use computers directly in their work. In these cases it may be preferable to hand out the surveys in paper form.

The case of the Dental School at Aarhus University, Denmark, where the questionnaire sent out as an electronic survey but the monitoring team was not able to get any answers of the surveys. One of the reason for this might be the computer is not a big part of their working routines In this case an solution could have been to hand the survey out in paper form the student should fill out while they were in the clinic.

6.3. Commissioning

In the case of the WSP office in Stockholm, Sweden, manually dimmable T5 pendant luminaires controllable through a hanging rope were installed. A single pull allowed to switch on or off, while keeping the rope pulled allowed dimming. None of the employees understood how the system worked. The light fixtures had very different light outputs since many employees dimmed by mistake and ignored how to get back to the original setting. The lessons learned in this case was that clear instructions should be given to the employees and probably written on the lamp in order to ensure a proper operation of the switching and dimming functions. Commissioning of the building shortly after a retrofit, by carrying surveys and measurements would allow identifying shortcomings in the functioning of the new installation, ensuring higher satisfaction and energy savings.

The case of the Dental School Clinic at Aarhus University, Denmark, where a daylight-linked dimming system was installed also provides another example where the absence of proper commissioning and correction directly after completion of the retrofit has had negative consequences on the proper operation of the daylight dimming system and energy savings. In this case, the users adjusted the illuminance to its highest level, so that no dimming occurred thereby jeopardizing the projected energy savings.

In contrast, in the case of the School of Electrical Engineering, Aalto University, Espoo, Finland, an automatic learning period was started directly after the installation of the new luminaires. This resulted in energy savings through optimized absence detection for different situations, light level compensation over the entire life cycle, and automatic daylight harvesting, thus demonstrating the success of the commissioning.

7. Conclusions

A monitoring toolbox was developed as part of IEA-SHC Task 50 on ‘Advanced Lighting Solutions for Retrofitting Buildings’. The procedure was tested in 25 case studies in ten countries. The case studies are presented with monitored data and key conclusions in a ‘Light Retrofit Advisor’ (freely available on Internet and portable devices). A few key lessons learned from the monitoring process are summarized below:

- Reducing energy use attributed to electric lighting was the main driver for the majority of the lighting retrofits monitored in this study.
- All retrofits monitored achieved improvements in either energy efficiency or lighting quality or both.
- The best overall results could be achieved when the focus was on an effective integration of energy performance, daylight and electric lighting.
- When the building design allows for good daylighting before the start of an electric lighting retrofit, it seems more likely that a retrofit can achieve good results with respect to user satisfaction and reduced lighting energy consumption due to effective integration with daylighting. However, as electric lighting is required for shorter periods in well-daylit spaces, lighting retrofits are less likely to be cost-effective as installation costs can easily outweigh the projected energy savings.
- When openings in the building envelope do not provide good views to the outdoors or effective daylighting in a space (e.g. because of the effective aperture being too small), building users might interact significantly less with available shading devices to regulate daylight and sunlight penetration into the space, typically resulting in even lower illumination from daylight. They might position the shading devices to avoid direct glare at specific times, but then forget to adjust the shading devices again to increase the daylight contribution later on. This could be observed before and after lighting retrofits. However, installing an integrated control system for shading and lighting to allow better daylight utilization could likely provide further energy savings potential in such a case.
- Replacing older fluorescent with appropriate LED lighting systems can lead to substantial energy savings for electric lighting. Lighting quality and user satisfaction can also be improved at the same time by providing better visual conditions in the spaces. It is, however, not recommended to just replace fluorescent tubes with LED tubes in existing luminaires other than those with diffusing panels, as it can lead to inappropriate light distribution patterns and significantly lower illuminance levels at the work plane.
- Heritage buildings present a special case, especially for daylighting and solar shading solutions, but sometimes also for electric lighting solutions, as there are typical limitations regarding alterations to exterior and/or interior building design features (depending on protection class and protected features). In the “Spanien” Public Pool and Spa in Aarhus, Denmark, the visual appearance of key luminaires had to be maintained as they are considered a part of the design heritage. Nevertheless, switching from fluorescent to dimmable LED lamps with flexible colour control inside existing luminaires resulted in a reduction in energy use and allows for the possibility to manually adjust illuminance levels and light colour depending on available daylight or other requirements.
- Upgrading older fluorescent lighting systems to newer ones can also provide benefits for both energy use and lighting quality.
- Control systems for electric lighting or solar shading devices, are frequently found to be poorly implemented, calibrated or commissioned, or perhaps too complex, resulting in reduced energy savings, annoyance of users or even in complete deactivation of the control system. This highlights the need for better guidance on the installation, commissioning and operation of lighting control systems.
- In general, the users prefer to have possibility to manually override of the control system
- The manually control of the electrical in the offices at Horsens Town Hall, Denmark, light by on/off switches are in general fulfilling the users visual needs, though a dimmable would be preferred, especially during wintertime with very low outside illumination.
- It is suggested that building owners implementing a lighting retrofit strongly consider monitoring appropriate performance metrics (see monitoring protocol) before and after such a retrofit to gauge the potential for the retrofit and later assess the success of the retrofit.